Roadmap for In Space Propulsion Technology

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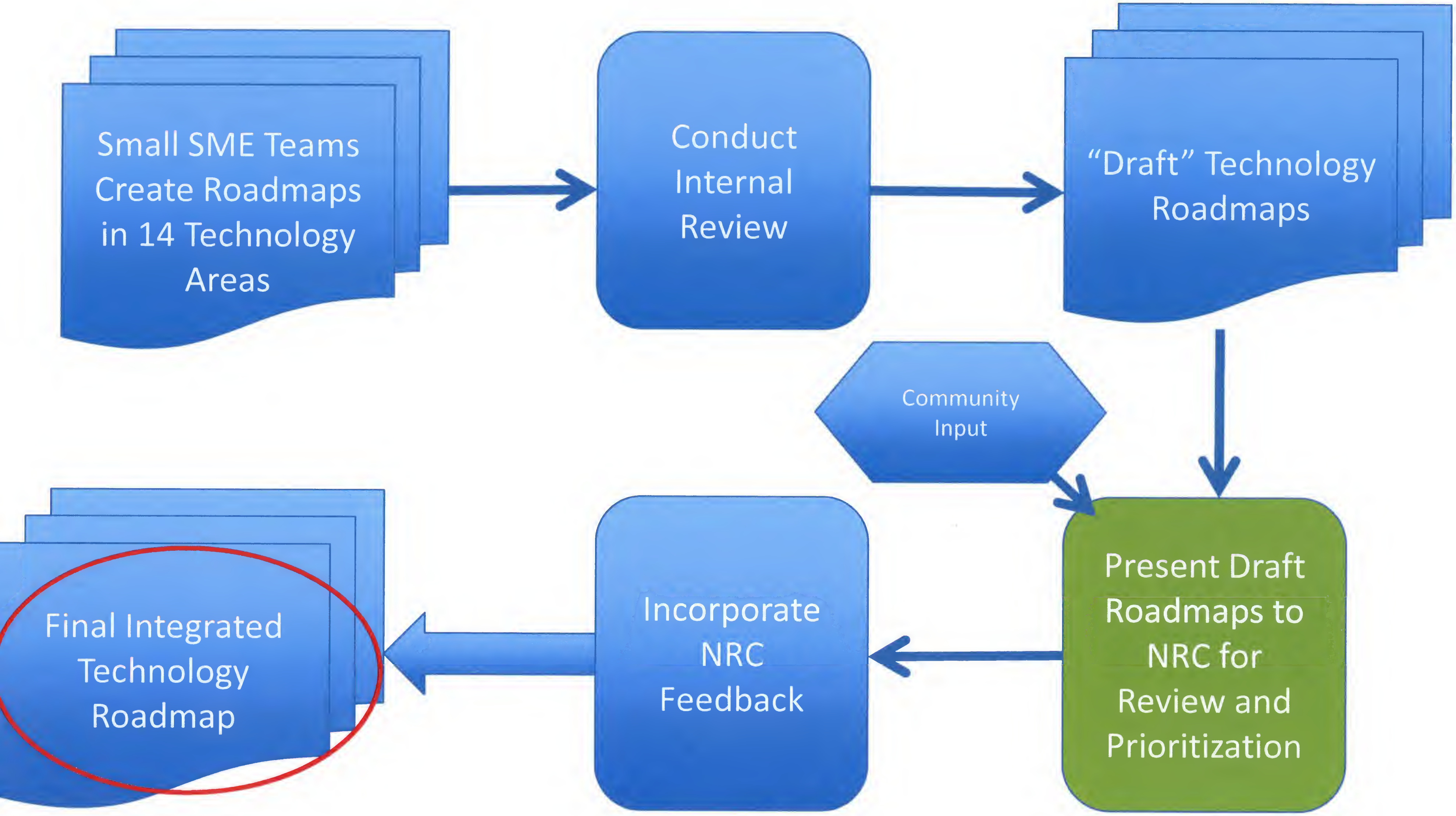
NASA OCT's Technology Roadmaps - Background

- In the Summer of 2010, NASA's Office of the Chief Technologist initiated an effort to develop an integrated space technology roadmap
- The roadmap was broken down into 14 Technology Areas (TA) selected based on
  - Significant technology investment was anticipated
  - Substantial enhancements to NASA mission capabilities are needed
- In-Space Propulsion Systems Technology is Technology Area 02 (TA02)

NASA OCT's Process to Create an Integrated Space Technology Roadmap



In-Space Propulsion Systems

Technology Area Scope

- For both human and robotic exploration, traversing the solar system is a struggle against time and distance.
- ***Advanced In-Space Propulsion technologies will enable much more effective exploration of our Solar System.***
  - Mission designers will be able to plan missions to "fly anytime, anywhere and complete a host of science objectives at the destinations" with greater reliability and safety and at lower cost.
- With a wide range of possible missions and candidate propulsion technologies with very diverse characteristics, the question of which technologies are "best" for future missions is a difficult one.
  - A portfolio of technologies should be developed so as to allow optimum propulsion solutions for a diverse set of missions and destinations.
- Once Earth orbit is achieved, high thrust is no longer required. Low thrust technologies can be used if they can be operated for long durations.
  - Several advanced in-space propulsion technologies offer performance that is significantly better than that achievable with state-of-the-art chemical propulsion.

This roadmap describes the portfolio of in-space propulsion technologies that can meet future space science and exploration needs.

Benefits

- Development of technologies within this TA will result in technical solutions with improvements in thrust levels, specific impulse, power, specific mass (or specific power), volume, system mass, system complexity, operational complexity, commonality with other spacecraft systems, manufacturability and durability.
- These types of improvements will
  - Yield decreased transit times
  - Increased payload mass
  - Decreased costs
  - Enable missions to new science/exploration targets
  - Provide potential propulsion breakthroughs that will revolutionize space exploration.

Traceability to NASA Strategic Goals

- The In-Space Propulsion Roadmap team used the NASA strategic goals and missions detailed in the following reference materials in the development of the roadmap:
  - Human Exploration Framework Team products to extract reference missions with dates
  - SMD Decadal Surveys
  - Past Design Reference Missions, Design Reference Architectures, and historical mission studies
  - In-Space Propulsion Technology Program concept studies
  - Internal ISS utilization studies.

Technology Area Breakdown Structure

- 2.0 In-Space Propulsion Technologies
  - 2.1 Chemical Propulsion
    - 2.1.1 Liquid Storable
    - 2.1.2 Liquid Cryogenic
    - 2.1.3 Gels
    - 2.1.4 Solid
    - 2.1.5 Hybrid
    - 2.1.6 Cold Gas/Warm Gas
    - 2.1.7 Micropropulsion
  - 2.2 Non-Chemical Propulsion
    - 2.2.1 Electric Propulsion
    - 2.2.2 Solar Sail Propulsion
    - 2.2.3 Thermal Propulsion
    - 2.2.4 Tether Propulsion
  - 2.3 Advanced (TRL <3) Propulsion Technologies
    - 2.3.1 Beamed Energy Propulsion
    - 2.3.2 Electric Sail Propulsion
    - 2.3.3 Fusion Propulsion
    - 2.3.4 High Energy Density Materials
    - 2.3.5 Animatter Propulsion
    - 2.3.6 Advanced Fission
    - 2.3.7 Breakthrough Propulsion
  - 2.4 Supporting Technologies
    - 2.4.1 Propellant Storage & Transfer

Top Technical Challenges from the Draft TA02 Roadmap

Rank	Description	Time
1	Power Processing Units (PPUs) for ion, Hall, and other electric propulsion systems	N
2	Long-term in-space cryogenic propellant storage and transfer	M
3	High power (e.g. 50-300 kW) class Solar Electric Propulsion	M
4	Advanced in-space cryogenic engines and supporting components	M
5	Developing and demonstrating MEMS-fabricated micropropulsion thrusters	N
6	Demonstrating large (over 1000 m^2) solar sail equipped vehicle on-orbit	N
7	Nuclear Thermal Propulsion (NTP) components and systems	F
8	Advanced, high performance, space storable propellants	M
9	Long-life (>1 year) electrodynamic tether propulsion system in LEO	N
10	Advanced In-Space Propulsion Technologies (TRL <3) to enable a robust technology portfolio for future missions.	F

N – near (present to 2016), M – mid (2017-2022), F – far (2023-2028)

(Timeframe for maturation to TRL 6)

Highest Technology Priorities* from the Final TA02 Roadmap

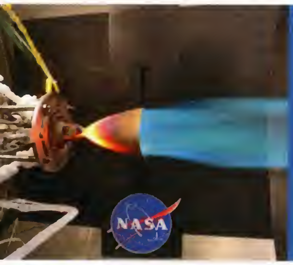
- ***Electric Propulsion***
  - Initial focus on high power solar electric propulsion (SEP) (~100 kW to ~ 1 MW
  - Continuing toward an ultimate goal of multimegawatt nuclear electric propulsion (NEP) capability.
- ***Propellant Storage and Transfer***
  - A technology at the "tipping point"
- ***(Nuclear) Thermal Propulsion***
  - A high-thrust/high-specific impulse propulsion
- ***Micropropulsion systems***
  - Development of miniaturized versions of chemical and non-chemical propulsion systems

*Based on Feedback from National Research Council Review

Summary

- This roadmap describes a portfolio of in-space propulsion technologies that can meet future space science and exploration needs.
  - Balances the need for technologies supporting both human and robotic exploration
  - Offer a diverse set of approaches to achieve new in-space propulsion capabilities across several promising technologies operating on very different physics
  - Identifies specific high-priority technologies
    - High Power Electric Propulsion, (Cryogenic) Propellant Storage and Transfer, (Nuclear) Thermal Propulsion, and Micro-propulsion.

Backup Slides



2.1 Chemical Propulsion

- Chemical Propulsion involves chemical reaction of propellants to move or control spacecraft.
  - Example technologies include:
    - **Liquids** - rocket systems using mono/bipropellants, high energy oxidizers, cryogenics (LO2/LH2 & LO2/CH4) as propellant.
    - **Gels** - fuels that are thixotropic (shear-thinning) that provide higher density, reduced sloshing, and leak resistance.
    - **Solids** - fuels that premix oxidizer and fuel and are typically cast formed.
    - **Hybrids** - technology that combines benefits of solids and liquids.
    - **Cold/Warm Gas** - uses expansion of inert cold/warm gas to generate thrust.
    - **Micropropulsion** - subset of above technologies (solids, gas, monopropellants) applied to small/microsatellite applications.

- Applications include primary propulsion, reaction control, station keeping, precision pointing, and orbital maneuvering.

- Technology Development in this area will result in improvements in thrust levels, volume, system mass, system complexity, operational complexity, and commonality with other spacecraft systems.

2.2 Non-chemical Propulsion

- Non-Chemical Propulsion serves same set of functions as chemical propulsion, but without using chemical reactants.
  - Example technologies include:
    - **Electric Propulsion** - systems that accelerate reaction mass electrostatically and/or electromagnetically.
    - **Solar or Nuclear Thermal Propulsion** - systems that energize propellant thermally.
    - **Solar Sail and Tether Propulsion** - systems that interact with the space environment to obtain thrust electromagnetically.

- Similar to Chemical, applications include primary propulsion, reaction control, station keeping, precision pointing, and orbital maneuvering.

- Technology Development in this area will result in improvements in thrust levels, specific impulse, power, specific mass (or specific power), and system mass.

2.3 Advanced Propulsion (<TRL3)

- Advanced Propulsion Technologies use chemical or non-chemical physics to produce thrust, but are lower technical maturity (TRL< 3) than those described in 2.1 and 2.2.
  - Example technologies include:
    - **Beamed Energy** - systems that use beamed laser or RF energy from ground source to heat propellant to generate thrust (e.g. lightcraft)
    - **Electric Sail** - system that uses a number of long/thin high voltage wires to interact with solar wind to generate thrust.
    - **Fusion** - systems that use fusion reactions indirectly (fusion power system to drive EP), or directly (fusion reaction provides kinetic energy to reactants used as propellant)
    - **High Energy Density Materials** - materials with extremely high energy densities to greatly increase propellant density and potential energy.
    - **Antimatter** – system that converts large percentage of fuel mass into propulsive energy through annihilation of particle-antiparticle pairs.
    - **Advanced Fission** – enhanced propulsion ideas that utilize fission reactions to provide heat to propellants (and in some cases utilize magnetic nozzles)
    - **Breakthrough Propulsion** – area of fundamental scientific research that seeks to explore and develop deeper understanding of nature of space-time, gravitation, inertial frames, quantum vacuum, and other fundamental physical phenomenon with objective of developing advanced propulsion applications.

- Predominant applications are in the area of primary propulsion, but some areas may also be applicable to reaction control, station keeping, precision pointing, and orbital maneuvering.

- Technology Development in this area will result in improvements in thrust levels, specific impulse, power, specific mass (or specific power), volume, system mass.